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GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

RESEARCH PROJECT INITIATION

Date: October 14, 1975

Project Title: A Study of Microearthquakes in the Southeastern United States

Project No: G-35-617

Principal Investigator Dr. L. T. Long

Sponsor: National Science Foundation

Agreement Period: From Sep. 1, 1975 Until Feb. 28, 1977*
*12 months budget period plus 6 months for submission of required reports, etc.

Type Agreement: Grant DES75-15756

Amount: $15,000 - NSF Funds (G-35-617)
1,239 - GIT Contrib. (G-35-319)
$16,239 - Total

Reports Required:
Final Report

Sponsor Contact Person (s):

Administrative Matters

Mr. F. G. Naughten
Grants Manager, Area 4
National Science Foundation
Washington, D. C. 20550
Phone: (202) 632-5965

Technical Matters

Dr. Roy E. Hausen
Geophysics Program
Earth Sciences Section
Division of Environmental Sciences
National Science Foundation
Washington, D. C. 20550

Assigned to: School of Geophysical Sciences

COPIES TO:
- Principal Investigator
- School Director
- Dean of the College
- Director, Research Administration
- Director, Financial Affairs (2)
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- Patent Coordinator
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- Photographic Laboratory
- Project File
- Other

RA-3 (9-75)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Post-it 80 Dtl

Date: 1/24/78

Project Title: A Study of Microearthquakes in the Southeastern United States

Project No: G-35-617

Project Director: Dr. L.T. Long

Sponsor: National Science Foundation

Effective Termination Date: 2/28/77

Clearance of Accounting Charges: N/A - All have cleared

Grant/Contract Closeout Actions Remaining: None

_ Final Invoice and Closing Documents
_ Final Fiscal Report
_ Final Report of Inventions
_ Govt. Property Inventory & Related Certificate
_ Classified Material Certificate
_ Other _____

Assigned to: Geophysical Sciences (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director—EES
Accounting Office
Procurement Office
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Director, Physical Plant
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Project File (OCA)
Project Code (GTRI)
Other _____

CA—4 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

OFFICE OF
THE DIRECTOR OF
FINANCIAL AFFAIRS

June 14, 1977

Division of Grants & Contracts
National Science Foundation
Washington, D. C. 20550

Gentlemen:

Enclosed in triplicate is the final fiscal report for Grant Number DES75-15756.

If you have any questions or desire additional information, please let us know.

Sincerely yours,

Evan Crosby //
Associate Director of
Financial Affairs

EC/bs
enclosure:

cc: Dr. L. T. Long
Dr. C. E. Weaver
Mr. E. E. Renfro
Mr. A. H. Becker
File

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

RESEARCH GRANT BUDGET & FISCAL REPORT

Form Approved
Budget Bureau No. 99-R0013

Please read instructions on reverse side carefully before completing this form.

INSTITUTION AND ADDRESS	NSF PROGRAM	GRANT PERIOD / REPORTING PERIOD
Georgia Institute of Tech. Atlanta, Georgia	Geophysics	GRANT PERIOD from 9/1/75 to 2/28/77 REPORTING PERIOD from 9/1/75 to 2/28/77 *

GRANT NUMBER	BUDGET DUR. (MOS.)	PRINCIPAL INVESTIGATOR(S)	GRANTEE ACCOUNT NUMBER
DES75-15756	12	Long	G-35-617

	NSF Funded Man Months Cal.	Acad.	Summ.	NSF AWARD BUDGET	CUMULATIVE GRANT EXPENDITURES *Do Not Round*
A. SALARIES AND WAGES					
1. Senior Personnel					
a. 1 (Co)Principal Investigator(s)			1	$ 1,850	
b. Faculty Associates					
Sub-Total				$ 1,850	$ 1,750.00
2. Other Personnel (Non-Faculty)					
a. Research Associates—Postdoctoral					
b. Non-Faculty Professionals					
c. 1 Graduate Students				3,000	
d. 2 Pre-Baccalaureate Students				1,355	
e. Secretarial—Clerical					
f. Technical, Shop, and Other					
TOTAL SALARIES AND WAGES				$ 6,205	$ 5,739.59
B. STAFF BENEFITS IF CHARGED AS DIRECT COST				278	159.26
C. TOTAL SALARIES, WAGES, AND STAFF BENEFITS (A + B)				$ 6,483	$ 5,898.85
D. PERMANENT EQUIPMENT					465.00
E. EXPENDABLE EQUIPMENT AND SUPPLIES				400	1,993.10
F. TRAVEL 1. DOMESTIC (INCLUDING CANADA)				1,700	1,607.07
2. FOREIGN					-
G. PUBLICATION COSTS				600	74.25
H. COMPUTER COSTS IF CHARGED AS DIRECT COST				670	834.49
I. OTHER DIRECT COSTS					
Equipment Repair				1,300	24.36
J. TOTAL DIRECT COSTS (C through I)				$ 11,153	$ 10,897.12
K. INDIRECT COSTS					
65% of Salaries & Wages = $4,033 Amount Requested				3,847	3,902.92
L. TOTAL COSTS (J plus K)				$ 15,000	$ 14,800.04
M. AMOUNT OF THIS AWARD (ROUNDED)				$ 15,000	
N. CUMULATIVE GRANT AMOUNT				$	
O. UNEXPENDED BALANCE (N. BUDGET MINUS L. EXPENDITURE)					$ 199.96

REMARKS: Use extra sheet if necessary

*No obligations were incurred outside the grant period of 9/1/75 to 2/28/77.

** Effective July 1, 1975 the approved Indirect Cost Rate changed to 68%.

FOR NSF USE ONLY
Final Fiscal Report Accepted
Grant Closed _____ Remains Open _____
By _____ Date _____
Grants Administration Section, Area _____

SIGNATURE OF PRINCIPAL INVESTIGATOR	TYPED OR PRINTED NAME	DATE
	Leland T. Long	6/13/77

I CERTIFY THAT ALL EXPENDITURES REPORTED ARE FOR APPROPRIATE PURPOSES AND IN ACCORDANCE WITH THE AGREEMENTS SET FORTH IN THE APPLICATION AND AWARD DOCUMENTS

SIGNATURE OF AUTHORIZED OFFICIAL	TYPED OR PRINTED NAME & TITLE	DATE
	Evan Crosby, Associate Director of Financial Affairs	6/14/77

FOR NSF USE ONLY

Organ. Code	F.Y.	Fund ID	Prog. Code	Ob. Class	O/Dres.	Award No.	Amd.	Inst. Code	Unexpended Balance	Trans.	Lot
									$		

NSF Form 98, JULY 1971

SUPERSEDES ALL PREVIOUS EDITIONS

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

SUMMARY OF COMPLETED PROJECT

Form Approved
OMB No. 99R0013

Please read instructions on reverse carefully before completing this form.

1. INSTITUTION AND ADDRESS		2. NSF PROGRAM	3. GRANT PERIOD
Georgia Institute of Technology Atlanta, Georgia 30332 (School of Geophysical Sciences)		Geophysics	from 9/1/75 to 2/28/77
4. GRANT NUMBER DES75-15756	5. BUDGET DUR. (MOS) 12	6. PRINCIPAL INVESTIGATOR(S) Leland Timothy Long	7. GRANTEE ACCOUNT NUMBER G35-617

8. SUMMARY (Attach list of publications to form)

The primary objective is to investigate the working hypothesis that major earthquakes occur in the southeastern United States because the geometries of structural units with anomalous rigidity and/or strength foster the concentration of stress in a deforming inhomogeneous crust.

The first technique used to evaluate the hypothesis was to obtain geophysical field data including gravity surveys and microearthquake monitoring of aftershocks. Second, existing data were analyzed with the new data. Third, theoretical computations of the stress distribution in inhomogeneous media were performed to evaluate the magnitude of possible stress amplification.

The most significant finding was that in the Coastal Plain of South Carolina, anomalously rigid crustal structures are directly correlated with seismic activity and earthquakes can be explained by the concentration of stress by such structures. Furthermore, such structures are typically associated with mafic intrusives. A secondary finding was that the working hypothesis could not be applied directly to earthquakes in the Piedmont Province or the Folded Appalachians. Instead, relative differences in the effective long-term thickness of the crust may modify its flexural rigidity and allow stress amplification in zones of anomalously thin or less rigid crust. A third finding is that significant differences in the spectral signature exists between microearthquakes in the Piedmont Province and in Folded Appalachians. The spectra imply that Piedmont Province and possibly reservoir induced earthquakes occur along existing fractures with little friction where-as microearthquakes in the Folded Appalachians rupture fresh rock or fracture along faults that have at least partially healed.

The most significant implication of the results is an explanation for the Great Charleston earthquake of 1886. If such an earthquake were to reoccur, extensive damage and lose of life could result. This research implies that potential sites for such earthquakes can be identified.

Project Title

A Study of Microearthquakes in the Southeastern United States; Evaluation of a Working Hypothesis.

9. SIGNATURE OF PRINCIPAL INVESTIGATOR/ PROJECT DIRECTOR	TYPED OR PRINTED NAME	DATE
	Leland Timothy Long	Oct. 31, 1977

NSF Form 98A (12-76) SUPERSEDES ALL PREVIOUS EDITIONS

Publications

Long, Leland Timothy (1976). Speculations Concerning Southeastern Earthquakes, Mafic intrusions, gravity anomalies, and stress amplification, Earthquake Notes, 47, 29-35.

Long, Leland Timothy (1976). Short-Period surface-wave attenuation and intensities in the Georgia-South Carolina Piedmont Province, Earthquake Notes, 47, 3-11.

Guinn, S. A. and Long, L. T. (1977). A gravity survey of the Dalton, Georgia area. Short Contributions to the Geology of Georgia Bulletin (in Press).

Jones, F. B., Long, L. T. and McKee, J. H. (1977). Study of the Attentuation and Azimuthal Dependence of Seismic Wave Propogation in the Southeastern U. S., Bull. Seism. Soc. Am., 67, 1503-1513.

Long, L. T. and Champion, J. W. (1977). Bouguer gravity map of the Summerville-Charleston, South Carolina epicentral zone and tectonic implications, in U. S. Geol. Survey, Prof. Pap. 1028-K.

Thesis

Marion, George E. (1977). A spectral analysis of microearthquakes that occur in the southeastern United States, Master's Thesis, Georgia Institute of Technology, Atlanta, Georgia, 154 pp.

Hsiao, Helmut Yung-An (1977). The "Stress Amplification" Mechanism for intraplate earthquakes applied to the southeast United States.

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF GEOPHYSICAL SCIENCES

Atlanta, Georgia 30332
(404) 894-2857

October 28, 1977

National Science Foundation
Washington, D. C. 20550

Attention: Program Director for Geophysics

Subject: Final Technical Letter Report

Principal Investigator: Leland Timothy Long, School of Geophysical Sciences, Georgia Institute of Technology

Grant Number: DES75-15756 extending from September 1, 1975 to February 28, 1977

Title: A Study of Microearthquakes in the Southeastern United States: Evaluation of a Working Hypothesis.

Dear Sir:

This final technical letter report is presented in two parts. The first part is a brief description of the research objectives and findings. Scientific collaborators, theses, and talks supported in part by the grant are presented in the first part. The second part consists of copies of some of the results, appropriate theses, and a manuscript submitted for publication.

NSF support on this grant has been very helpful in the development of a viable geophysics program at Georgia Tech. The contribution of NSF support to the goals of the principal investigator and the success of the geophysics program is greatfully acknowledged.

Respectfully submitted,

Dr. Leland Timothy Long
Principal Investigator

Final Technical Letter Report
National Science Foundation
Grant Number DES75-15756

A STUDY OF MICROEARTHQUAKES IN THE SOUTHEASTERN UNITED STATES; EVALUATION OF A WORKING HYPOTHESIS

PART I
Research Objectives and Findings

Objectives

The primary objective of the proposed work was to investigate the working hypothesis that:

"Major earthquakes occur in the southeastern United States because the geometries of structural units with anomalous rigidity and/or strength foster the concentration of stress in a deforming inhomogeneous crust."

Secondary objectives were directed largely at obtaining significant field data and theoretical computations to show the validity of the hypothesis. The field data included a gravity survey of the Maryville, Tennessee, area and microearthquake monitoring of known or suspected seismic activity. The theoretical studies included numerical modeling the stress in structures with inhomogeneous rigidity and computing the spectral signature of microearthquakes.

Findings

Two significant conclusions have been derived from this research.

1. In the Coastal Plain of South Carolina anomalously rigid structural units typically associated with mafic intrusives of the crust are directly correlated with seismic activity and can be explained by the concentration of stress. This conclusion and documentation has been submitted to the BSSA for possible publication. A draft of the submitted manuscript is attached.

2. Earthquakes in areas (of the southeast) other than the Coastal Plain do not satisfy as simple an explanation. Instead, relative differences in the effective long-term thickness of the crust may modify its flexural rigidity and allow stress amplification in zones of anomalously thin or less rigid crust. A proposal to study this aspect of "stress amplification" is being prepared for submission to NSF.

Many other significant findings have been supported in part or have benefited from work on this grant.

1. The gravity survey of the Maryville, Tennessee area was completed and is attached with a geologic map. No large mafic intrusive in the crust could be identified to associate with the Maryville epicenter. There is, however, a correlation of the gravity with surface geology and also with the intensity data given by Bollinger et al. (1976). Publication is not anticipated unless significant additional data can be obtained.

2. Aftershock monitoring of the Conasauga earthquake of February 4, 1976 did not yield any aftershocks. An analysis of the data pertinent to this earthquake were presented at the Eastern Section Seismological Society of America meeting in Ann Arbor, Michigan. Publication is anticipated within one year.

3. A gravity survey performed in association with the aftershock study of the February 4, 1976 earthquake was completed but the area of investigation did not include the revised epicenter. Analysis of the gravity data and a refraction line across the area have been accepted for publication by the Georgia Geological Survey.

4. Numerical models of structures with inhomogeneous rigidity have been computed in order to evaluate the magnitudes of the stresses that can be obtained by geometrical amplification of applied lower-level stresses. This was the topic

of a Masters Theses by Helmut Yung An Hsiao. A copy is attached. Results from this work were presented in talks and are summarized in the paper submitted to BSSA.

5. The spectral signature of microearthquakes in the Southeastern United States was examined in detail by George Marion in his masters' thesis entitled "A Spectral Analysis of Microearthquakes that Occur in the Southeastern United States". A copy of the thesis is attached. Significant differences in the spectral signature between events in the Piedmont Province and the Folded Appalachians were discovered. Microearthquakes at the Jocassee reservoir show a dominant W^{-3} decay which implies movement on lubricated surfaces. The Clark Hill Reservoir events showed decay rates of W^{-2} to W^{-3} indicating less of a dependence on a lubricated fault plain. In contrast, the Maryville, Tennessee, earthquakes showed W^{-1} to W^{-2} high-frequency decay which implies a low rupture velocity and the possible breaking of fresh rock. However, all of the events studied were of magnitude 2.5 or less. In a subsequent proposal I hope to investigate whether this relation extends to large magnitude events.

6. The stress amplification hypothesis was also applied to an interpretation of gravity data near the Charleston epicenter. This analysis has been accepted for publication as a chapter in U. S. Geological Survey Professional Paper 1028K. Reprints will be submitted when available. This publication presents an argument that the structure of the crust and the location of recent and historical seismic activity are compatible with stress amplification as an explanation for the Great Charleston earthquake of 1886.

Publications

Long, Leland Timothy (1976). Speculations Concerning Southeastern Earthquakes, Mafic intrusions, gravity anomalies, and stress amplification, Earthquake Notes, 47, 29-35.

Long, Leland Timothy (1976). Short-Period surface-wave attenuation and intensities in the Georgia-South Carolina Piedmont Province, Earthquake Notes, 47, 3-11.

Guinn, S. A. and Long, L. T. (1977). A gravity survey of the Dalton, Georgia area. Short Contributions to the Geology of Georgia Bulletin (in Press).

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Long, L. T. and Champion, J. W. (1977). Bouguer gravity map of the Summerville-Charleston, South Carolina epicentral zone and tectonic implications, in U. S. Geol. Survey, Prof. Pap. 1028-K.

Thesis

Marion, George E. (1977). A spectral analysis of microearthquakes that occur in the southeastern United States, Master's Thesis, Georgia Institute of Technology, Atlanta, Georgia, 154 pp.

Hsiao, Helmut Yung-An (1977). The "Stress Amplification" Mechanism for intraplate earthquakes applied to the southeast United States.

April 1, 1975 - 1977.

Talks and Abstracts

Long, L. T. (1975). The 1886 Charleston, S. C. earthquake and its relation to the seismicity of the southeastern United States (Abstract) Earthquake Notes, 46, 50. (Presented at Eastern Section, Seism. Soc. Am. Annual Meeting, St. Louis, November 1975)

Long, L. T. (1975). Isostatic Compensation and tectonics in the southeastern United States (Abstract) EOS, 56, 454. (Presented at Am. Geophys. Union Annual meeting, Washington, D. C., June 1975)

Long, L. T. and Hsiao, Yung An Helmut (1976). The "Stress Amplification" mechanism for intraplate earthquakes applied to the southeastern United States (Abstract) in Abstracts with Programs 8, Geological Society of America, p. 221. (Presented at Southeastern Section, Geological Society of America, Arlington, Virginia, March 1976).

Long, L. T. (1976). The Summerville-Charleston and Bowman epicentral zones and their relation to the seismicity of the Southeastern United States (Abstract), Earthquake Notes, 47, 19. (Presented at the Seismological Society of America annual meeting, Alberta, Canada, May, 1976).

Long, L. T. and Guinn, S. A. (1976). The Dalton, Georgia Earthquake of February 4, 1976, (Abstract) Earthquake Notes, 47, 5. (Presented at the Annual Meeting of the Eastern Section, Seismological Society of America. Ann Arbor, Michigan October, 1976).

Guinn, S. A. and Long, L. T. (1977). A Gravity Survey of the Dalton, Georgia Area. (Abstract) in Abstracts with Programs 9 Geological Society of America, p. 143. (presented at Southeastern Section, Geological Society of America, Winston-Salem, N. C., March 1977).

Marion, George E., and Long, L. T. (1977). Spectral Analysis of Southeastern United States Microearthquakes (Abstract) in Abstracts with Programs 9 Geological Society of America, p. 165 (Presneted at Southeastern Section, Geological Society of America, Winston-Salem, N. C., March, 1977).

Long, L. T. (1977). Regionization of the South Carolina Seismic Zone (Abstract) EOS, 58, 432. (Presented at Am. Geophys. Union Annual Meeting, Washington, D. C., June, 1977).

Collaborators

The research supported by the NSF Grant has encouraged a cooperation and interchange of data with investigators at other organizations with interests in the Southeast United States. Intensity data and information on events of regional interest have been regularly submitted to the U. S. Geological Survey and NOAA. The U. S. Geological Survey has provided film copies of the S. C. Net data for events we have recognized at Georgia Tech stations and could specifically request. The U. S. Geological Survey also cooperated during the early phases of the Charleston investigation with the preparation of the Summerville-Charleston Gravity map and its tectonic implications. The spectral analysis of Jocassee data were facilitated by cooperation with Duke Power Co. and the Law Engineering Testing Co. Nuclear Regulatory Commission support in the Clark Hill Reservoir Area made possible a significantly enhanced study of the spectral characteristics of microearthquakes.

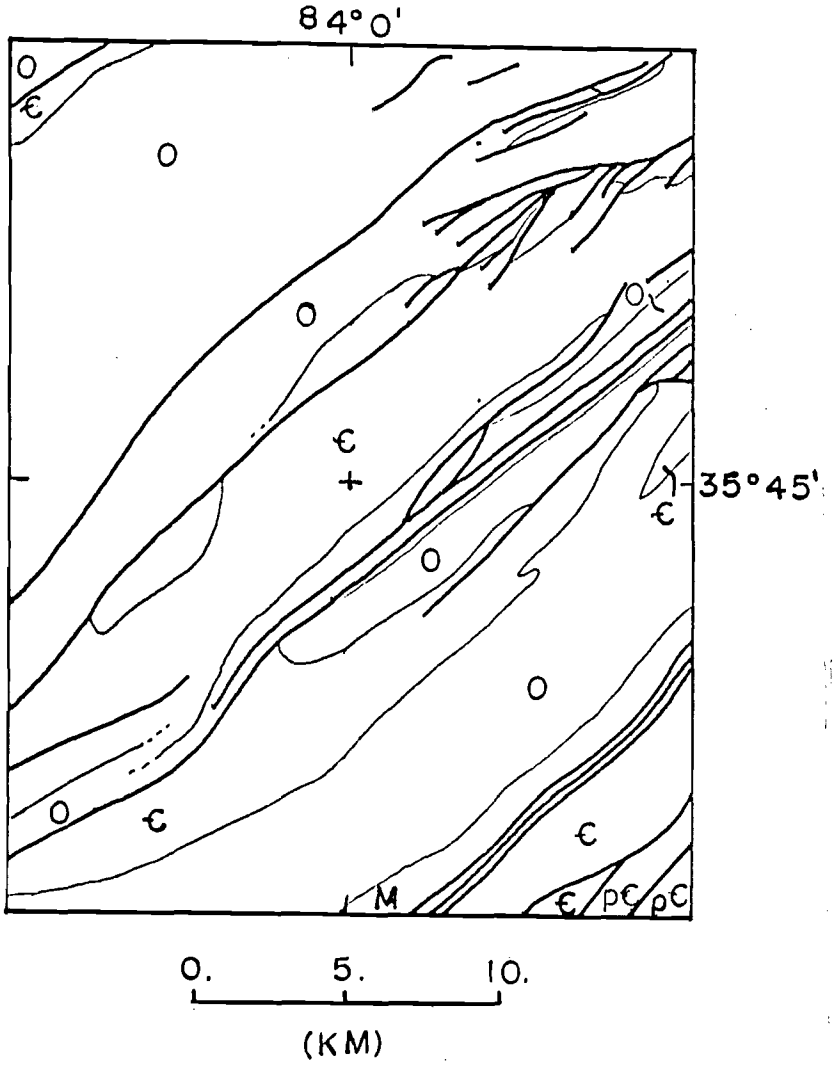
Grant funds have provided direct or indirect support for geophysics students at Georgia Tech. In particular, Helmut Yung-An Hsiao and George E. Marion as graduate research assistants received direct assistance in their thesis work from the grant. Stewart Guinn as a graduate research assistant received direct assistance for research related to the grant. Stewart Guinn's thesis is on focal mechanisms of southeast United States Earthquakes. These three students are currently employed in seismology or exploration geophysics. Bill Volz as a graduate research assistant obtained support for the Maryville, Tennessee, gravity survey.

Comments:

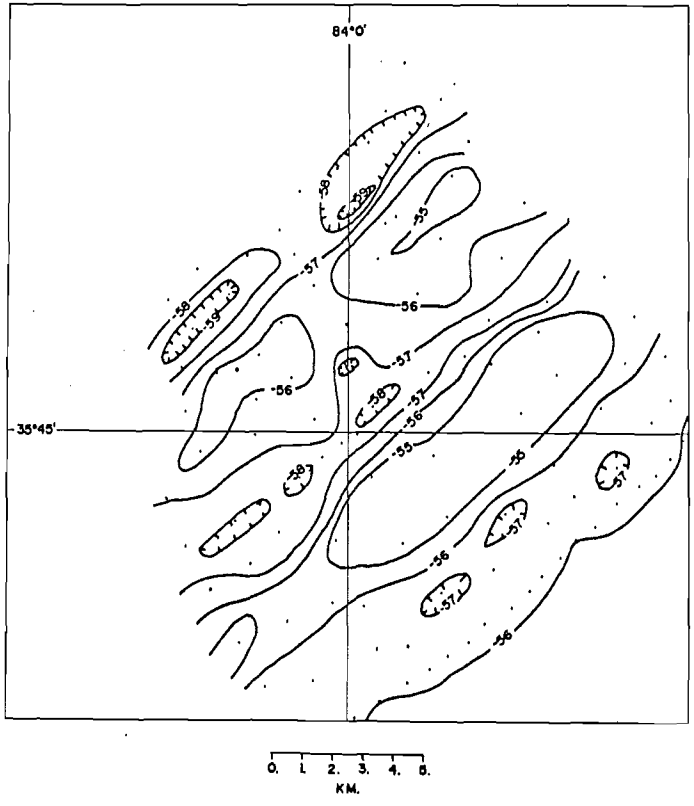
The work on this grant has shown the extreme importance of proper and complete instrumentation. Some of our earlier efforts in retrospect, were seriously hampered by instrumentation defficiencies. The tape unit employed

at Bowman, S. C. and for the last time at Maryville, Tennessee, was limited by lack of supporting portable microearthquake recorders. Consequently, focal mechanisms and reliable, rapid locations were not possible. Hence, Georgia Tech's contribution to the Maryville study was insufficient to allow participation in the analysis. However, the spectral data from that aftershock sequence when analyzed by George Marion revealed characteristics unique to the area and important conslusions relative to the mode of faulting. As a second example, we developed three low-cost tape recorder systems for 15 to 300 Hz which were able to resolve the high-frequence decay of very small earthquakes in the Clark Hill Reservoir Area and Jocassee Reservoir Area. The data obtained by these systems are unique and have lead to an hypothesis concerning the mode of fault rupture in reservoir areas. However, we need additional instruments to allow focal mechanism determination of the events for which spectra are obtained to allow correlations of spectral characteristics with positions on the focal sphere.

The work on this grant has supported analysis of a unique and perhaps radically different concept of earthquake tectonics. It is, perhaps, one of the few studies to examine the influence of crustal inhomogenieties on the occurrence of earthquakes in the interior of a plate. As a consequence a causal relation has been hypothesized which may explain why earthquakes occurr in the interior of some plates.



Geology



Simple Bouguer Gravity Anomaly

Maryville, Tennessee, area gravity study of the aftershock zone of the November 30, 1973 earthquake.